TEST PLAN

Adjustable Focus Optical Correction Lens (AFOCL)

Contract NAS8-00118

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Introduction:

This report describes a metrology plan that was developed for the characterization of PLZT-based devices, such as the Adjustable Focus Optical Correction Lens (AFOCL) in support of and as part of the deliverables for NASA contract NAS8-00118. The areas to be investigated include intensiomentric effects (those that limit or alter the intensity of the light transmitted through the optic); interferometric effects (the phase change induced through the optic); and polarimetric effects (evaluating the differential lag between two polarization states propagating through the optic). These distinct phenomena are often coupled together in real applications consequently, there is a need to develop different standardized testing apparatus to: (1) isolate one effect from another; (2) gather information for understanding the physical effects; (3) anchor wavefront corrector modeling efforts; (4) develop the ability to decouple different effects; (5) demonstrate the suitability of PLZT technology to perform wavefront correction.

The Center for Applied Optics (CAO) at the University of Alabama in Huntsville (UAH) is skilled in the characterization of transmission wavefront shaping devices using traditional interferometers available within the CAO Optical Metrology Laboratory and their Advanced Polarization Test Facility. Besides the imaging and interferometers available, the polarimetry facility has at its disposal, a Mueller Matrix Imaging Polarimeter (MMIP) which is well suited to the characterization of SLMs, polarizers, and thin film coatings within the visible and near-IR spectrums. In addition, the phase-shifting interferometry facilities at NASA-MSFC and the unique interferometers they processes are some of the most advanced available and may be of value especially for performing real-time optical performance evaluation of AFOCL test components.

Proposed Testing Schedule:

Year 1: <u>Initial Optical Characterization of PLZT Test Device as Undertaken</u>.

A PLZT test device has been commercially procured from an outside vendor: The University of California in San Diego (UCSD) in partnership with New Interconnect Packaging Technologies (NIPT) Inc. The device will be subjected to several tests to characterize the optical performance of the device at wavelengths of interest. The transmission efficiency and diffraction efficiency of the PLZT bulk material and the active device is of interest. A series of laboratory measurements at discrete laser wavelengths is proposed based on the location of appropriate lasers for testing from visible through near-IR. The transmission, reflectance and diffraction efficiency of the element will be evaluated and compared to a base-line measurement made at 632 nm (HeNe laser). The optical performance of the base PLZT material at IR wavelengths is a fundamental material measurement and is critical to future use of the devices at IR wavelengths. A measurement of the diffraction efficiency of the device is of secondary value. The characterization process should determine if the diffraction efficiency of the devices follows a classical wavelength scaling law.

Further measurements shall be attempted to evaluate imaging quality. This can be accomplished through an analysis of the point spread function or Modulation Transfer Function (MTF) of the test device. While the CAO has equipment and expertise in conducting an MTF measurement, it is extremely complicated and time consuming. Therefore, it is suggested to initially perform a simpler imaging test using a laser input while recording the resulting focused energy output from the device. If the device is well constructed and well behaved in its performance, the result should be similar to a conventional lens and any optical aberrations present due to the PLZT material should be evident as a deviation in the size of the diffraction limited spot (blur), the presence of diffracted energy into higher orders surrounding the focused spot (a variation in Strehl), and/or a variation or spread in the location of the focused energy away from the optical axis (a bias towards optical wedge, spherical, comma, or other higher order aberrations).

Year 2: <u>Proposed Design and Procurement of a Variable Focusing PLZT Lens for the Infrared</u>.

Based on costs and capabilities explored during the first year, it is proposed that a specially designed variable focusing device shall be designed and procured from a commercial vendor. The versatility of the fabrication process shall be explored at this step to determine technological and cost driven limitations. In addition, the ability to make hybrid refractive-active components will be investigated to determine manufacturability, ease of use, and quality. Test devices shall then be characterized to measure response time, point spread function, and intrinsic aberration. The data collected shall be compared to anticipated values to anchor and validate AFOCL design and modeling tools for the infrared spectrum. These tests should support future specification of PLZT and specifically AFOCL devices.

Year 3: Demonstrate the Cascading PLZT Devices to Perform Complex Wavefront Correction.

Through the experience gained in Year 2, and if funding is available, special test articles shall be specified and procured commercially to be linked in a cascading or stacked configuration to demonstrate the ability to do complex wavefront shaping for possible aberration correction. By creation of a controlled input wavefront (known aberrations) and subsequent measurement of the output wavefront (final aberrations) that has been transmitted through a series of PLZT devices, along with characterization of the individual components, the capability of PLZT devices to perform wavefront correction will have been demonstrated. Finally, all of the experimental data collected shall be incorporated with the theoretical performances to create a computer-based model that can be used as a design tool for future AFOCL devices.

Image Quality Testing:

The testing of the initial test device supplied by UCSD/NIPT was conducted at HeHe wavelengths (λ=632 nm) for ease in setup and data acquisition. The ability of the AFOCL to focus the incident energy of a HeNe laser is shown in Figure 1. The images were taken using a CCD camera and the test setup shown in Figure 2. Two different locations for the CCD camera were selected to attempt to better define the true focal length of the device.

There is no voltage to the AFOCL device in Figure 1 with the unexpanded HeNe laser transmitted through the 4 mm diameter aperture of the device and the resulting intensity pattern is shown. Then, the ring electrodes are provided current through the connections and the device voltage is increased towards an optimal calculated voltage. The underpowered device is operating as a very poor diffractive optic collecting lens at lower voltages because the efficiency of the diffractive structure is rather low. As the voltage increases, the efficiency of the diffractive increases and the focusing of the light become more pronounced as shown in smaller and more circular central focused spot. The tabulated data on the focusing of the spot as evident in the decrease in the spot diameter is shown in Figure 3.

The scattering of light around the AFOCL device is attributed to two things. The optical quality of the mounting of the AFOCL is less than desired with adhesive optical cement clearly visible at the periphery of the AFOCL active area. This cement will affect the transmitted wavefront quality and can likely be minimized or eliminated with more careful attention to the mounting procedures. Similar and better mounting procedures are readily available through commercial vendors and companies such as CCD camera manufactures who mount cover plates over CCD arrays and would not be difficult to implement. An alternative would be to place a nonelectrically conducting index matching fluid over the surface of the AFOCL that contains the excessive optical cement. This should minimize the aberrations and give a truer picture of the operation of the device. The second effect contributing to the scattering of the light is believed to be the optical effects of the electrodes within the field of view. This effect is small but observable and has been modeled in the simulations (Figure 4).

Interferometric Testing:

The testing of the AFOCL is emphasizing the interferometric measurements of the AFOCL device. The device was placed in the test setup as shown in Figure 5 and 6. The test is a double pass interferogram of the AFOCL with three different operational states: positive lens, voltage off, and negative lens. The maximum voltage for both the positive and negative lens configurations was 250 Volts.

The Wyko Tymann-Green Interferometer uses a HeNe laser transmitted through the device. No physical aperture was used in these tests to mark the 4 mm diameter active area of the device. Instead, software in the computer integrated into the interferometer was used to select a digital aperture for data processing. The digital aperture size and location was based on the AFOCL device. The metal voltage supplying leads were used to center the digital aperture on the interferogram and the diameter was selected based on the approximate 4 mm active area. While the aperture is not exactly 4 mm diameter, the same aperture was used for all data sets so the interferograms would be consistent.

Typical interferograms are shown in Figure 7. Several interferograms were collected and stored at each of the configurations (positive lens, no voltage, and negative lens). The raw data was then transferred into the Quick Fringe software for reduction. In Quick Fringe, the locations of the fringe centers on the raw interferograms are determined and the fringes are digitized. In this fashion, contour plots of the transmitted wavefront are generated (Figure 8) for every one of the raw interferograms. All of the interferograms within one configuration are then averaged together to create the synthetic fringe plots shown in Figure 9.

Conclusions:

As expected, the optical power is greater in the positive lens configuration than the negative lens configuration. However, there appears to be significant amounts of bias in the lens to begin with, even when no voltage is applied. This is consistent with the imaging data acquired and is likely attributable to the mounting procedure used by NIPT and UCSD. The substandard quality of the optical mounting and fabrication of the device places an overwhelming bias on the measurements making it difficult to separate performance from poor manufacturing. While issues of optical bonding and attachment of electrodes are all technologies readily available from the electronics industry, NIPT has very limited access to equipment and processes to improve their processes. Given the current limited capabilities of UCSD/NIPT, it is doubtful that the quality of their production could be significantly increased without unreasonable increases in financial backing that is not evident at this time.

Proposed Plan of Action:

- Continue with the testing of the existing device, especially advanced interferometry to better characterize the performance of the device in spite of the strong bias from the poor production processes.
- Expand the optical testing to investigate polarization effects and optical material effects and investigate using the Mueller Matrix Imaging Polarimeter.
- Delay procurement of another device until either: (1) NIPT demonstrates greater capability in bonding processes; (2) an alternative vendor can be identified.

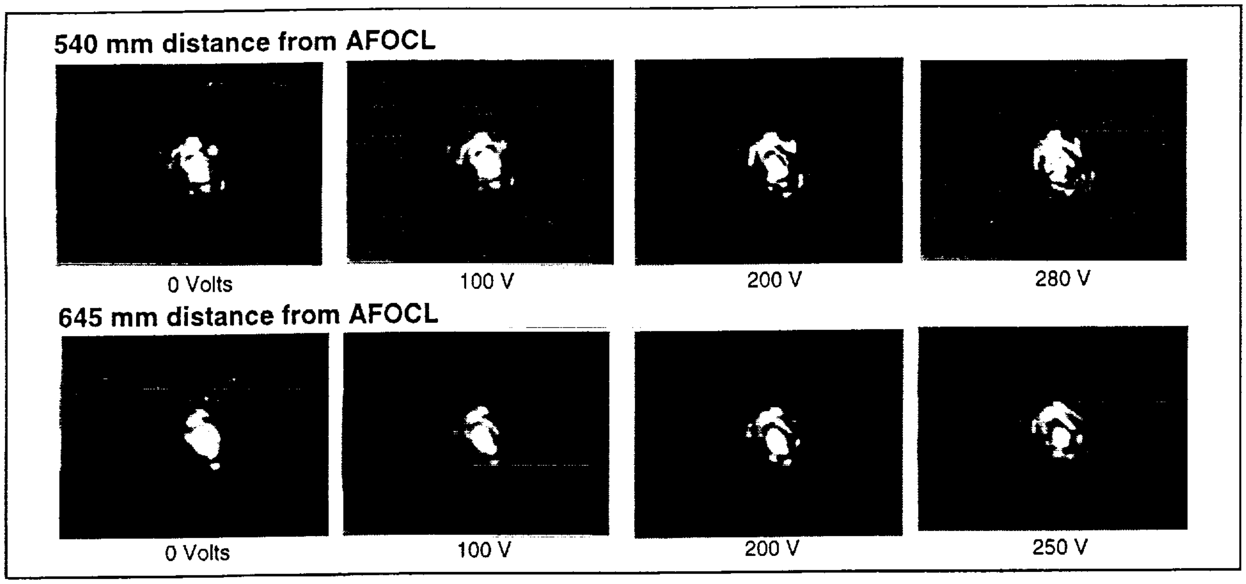


Figure 1. Focusing of HeNe Laser by AFOCL

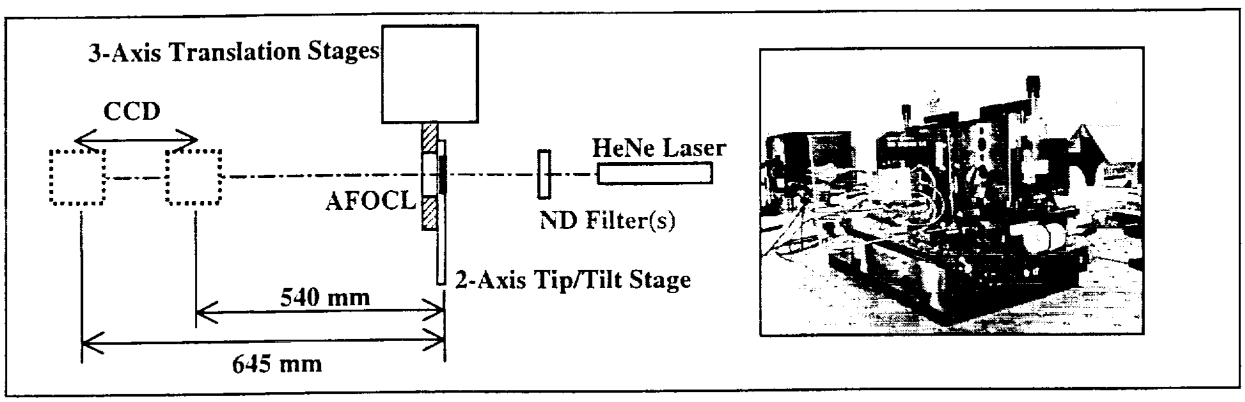


Figure 2. Test Setup for AFOCL Initial Checkout Test.

Measured 540 mm from AFOCL			
	0 Volts	**280 Volts**	**Reduction**
Diameter	6.10	3.81	37.50 %
Area	29.22	11.40	60.99 %

Measured 645 mm from AFOCL			
	0 Volts	**250 Volts**	**Reduction**
Diameter	7.37	42.66	37.07%
Area	5.08	20.27	52.49%

Figure 3. Tabulated Data from Initial Checkout Test.

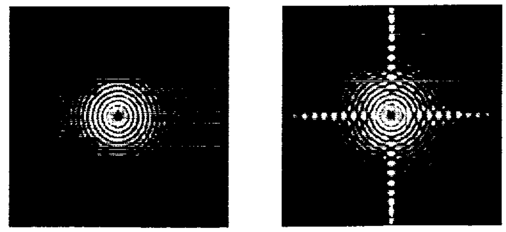
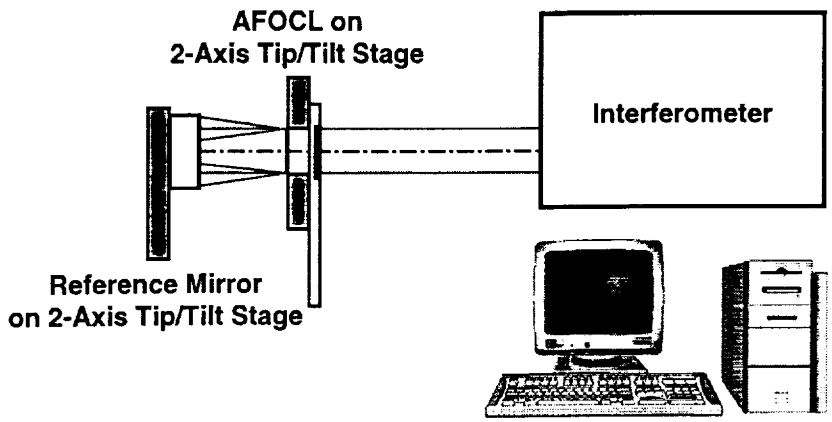


Figure 4. Modeled Effects of the Electrodes on the Diffracted Light.



- Wyko Twymann-Green Interferometer
- Quick Fringe Analysis Software

Figure 5. Interferometric Test Setup.

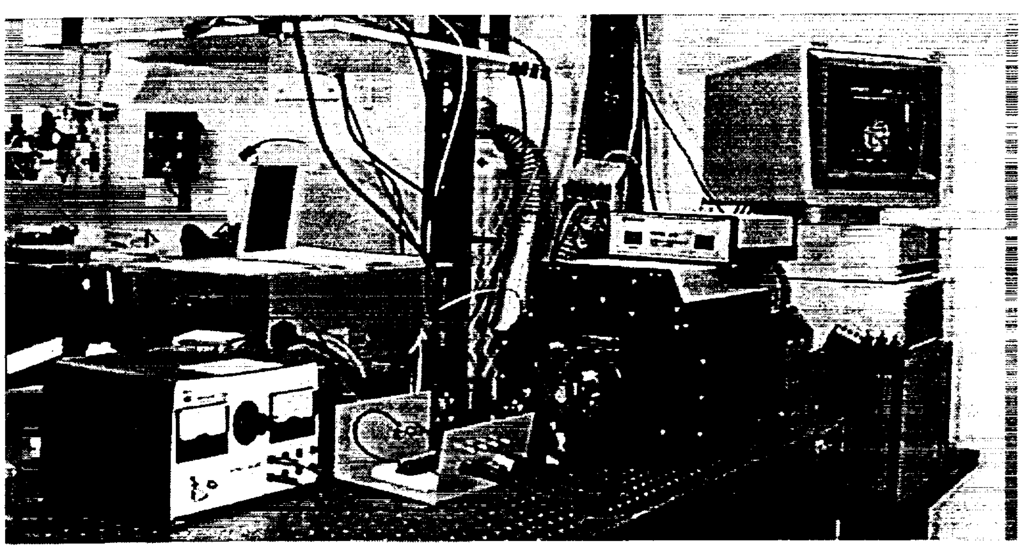
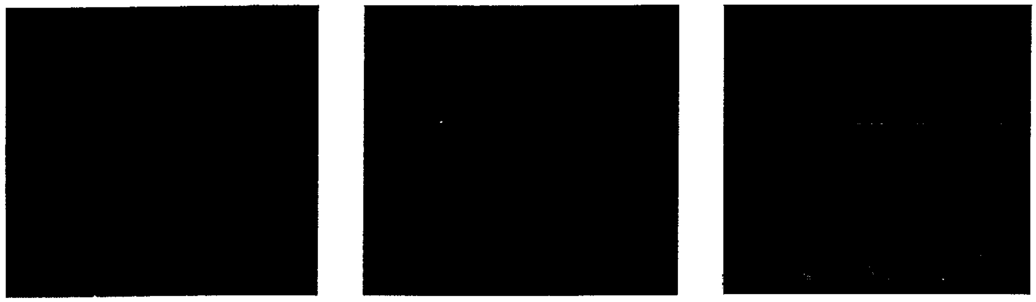
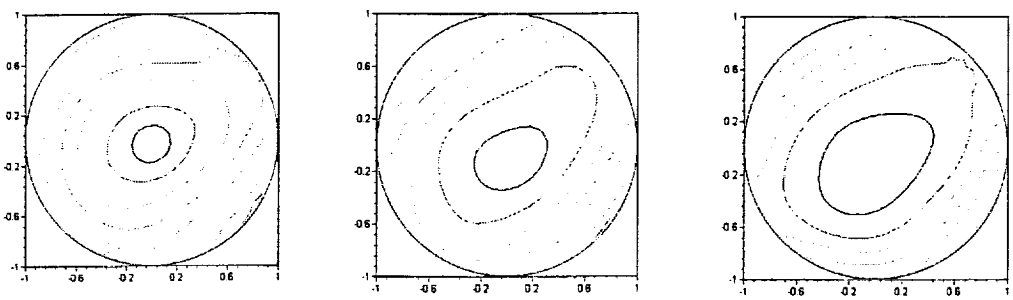


Figure 6. Interferometric Test Setup.



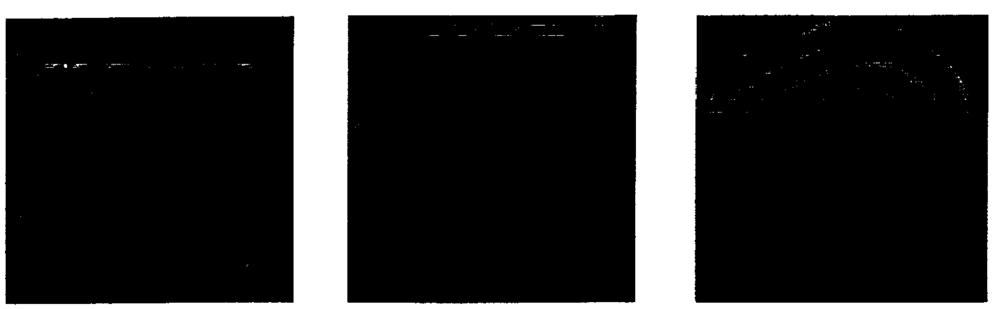
Positive Lens   Zero Voltage   Negative Lens

Figure 7. Typical Interferometric Raw Data.



Positive Lens   Zero Voltage   Negative Lens

Figure 8. Typical Reduced Data Showing Fringe Contour Plots.



Positive Lens   Zero Voltage   Negative Lens

Figure 9. Averaged Data to Generate Synthetic Fringe Plots.

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